High p_T Single Identified Particles in Various Systems, Various Collision Energies, and Several Scaling Variables

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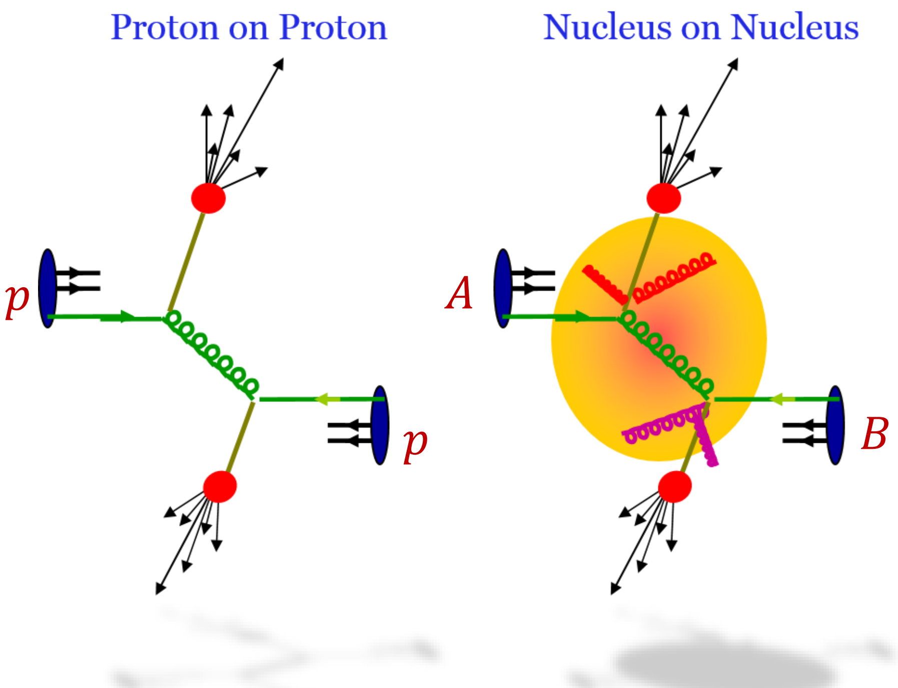
Medium Opaqueness to Color

- Hot dense medium formed in relativistic heavy ion collisions → opaque to colored particles



- Measured by quantifying energy loss → gain information of medium properties

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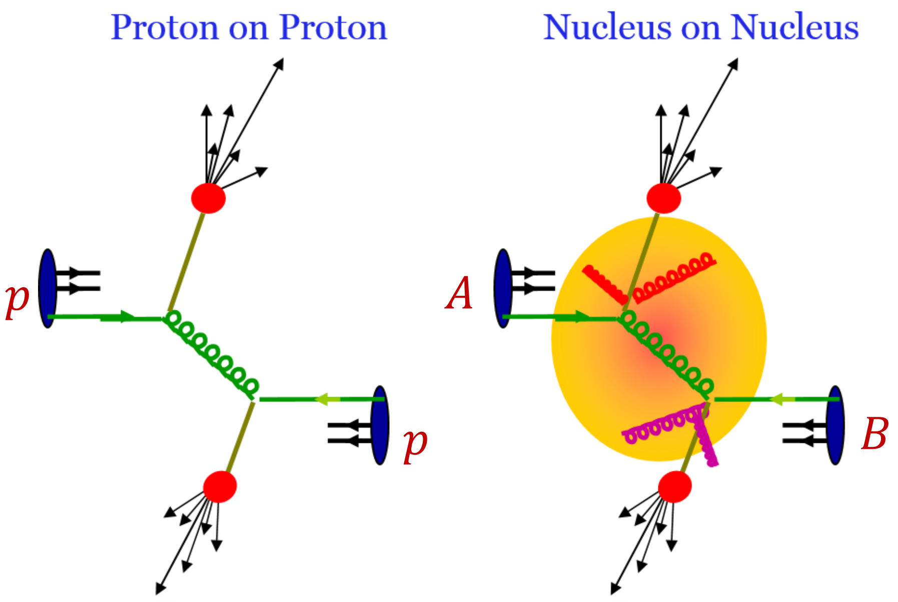
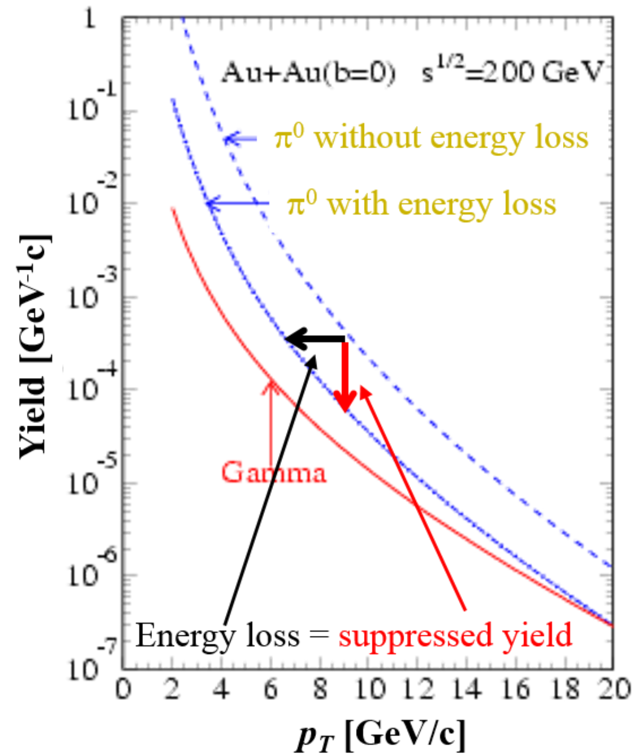




X.-N., Wang, PRC **58** (1998)2321

Energy Loss

- Energy loss description → non-trivial
  - Original parton energy
  - Decelerated parton energy

  Not easily accessible
- Back-to-back photon-jet pairs: reduced rate → α_{em}
- Jets alone not affected by α_{em}, but
  - Definition of jets → ambiguity
  - Measurement of jets → challenging
- Use high p_T hadrons as proxies → leading hadron as a measure of jet energy

Characterization of Energy Loss

- Assume: Fragmentation Function (FF) same for p+p and A+A
- Nuclear Modification Factor

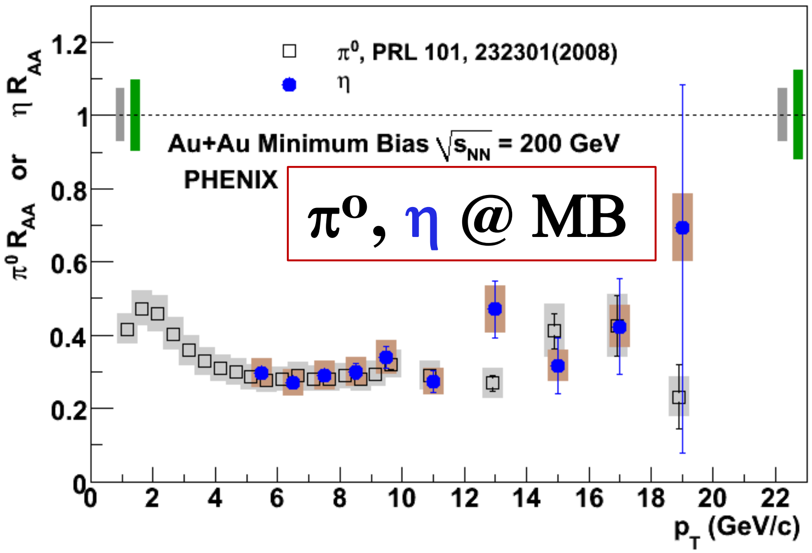
$$R_{AB}(p_T) = \frac{(1/N_{AB}^{evt})d^2N_{AB}^h/dp_T dy}{\langle T_{AB}\rangle \times d^2\sigma_{pp}^h/dp_T dy}$$

σ_{pp}^h: production x-sec
$\langle T_{AB}\rangle = \langle N_{coll}\rangle/\sigma_{pp}^{inel}$: nuclear overlap function
$\langle N_{coll}\rangle$: # of binary collisions

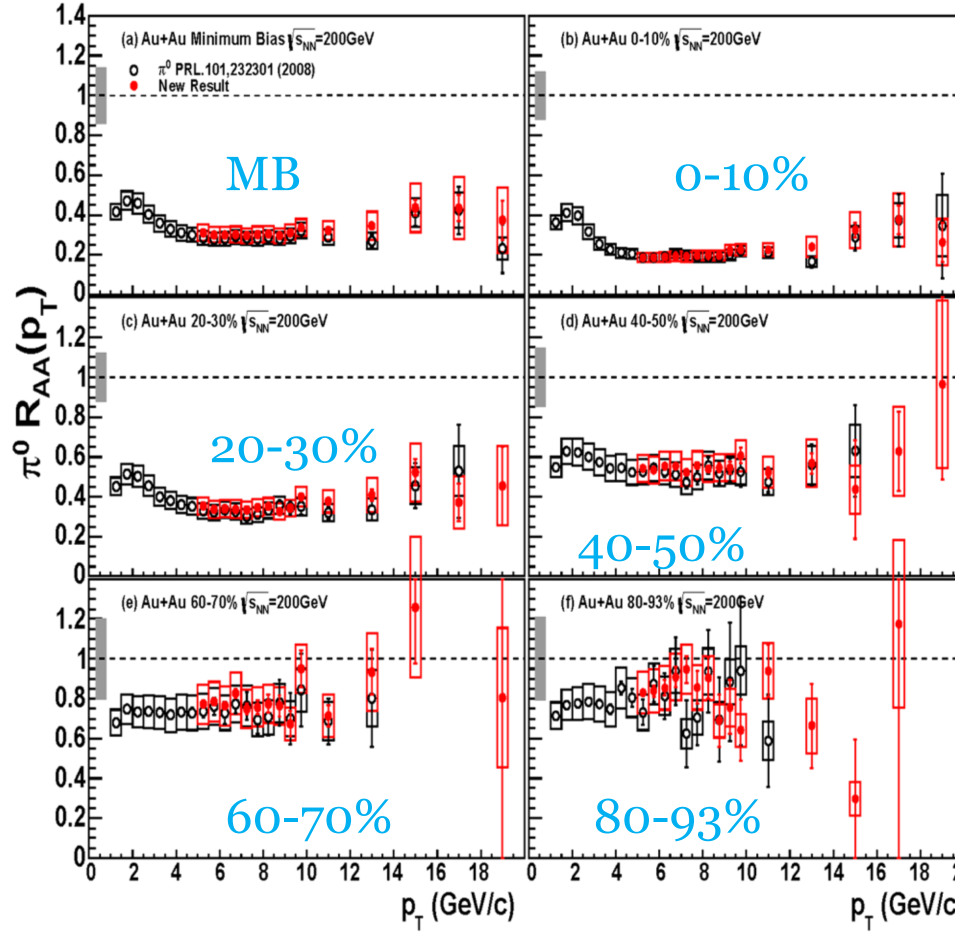
- $R_{AA} = 1 \rightarrow$ no nuclear - medium effect
- $R_{AA} < 1 \rightarrow$ suppression

Characterization of Energy Loss

- High p_T hadron R_{AA}
  - Measured in Au+Au 200GeV
  - Same FF for $R_{AA} \rightarrow \pi^0$ and η consistent



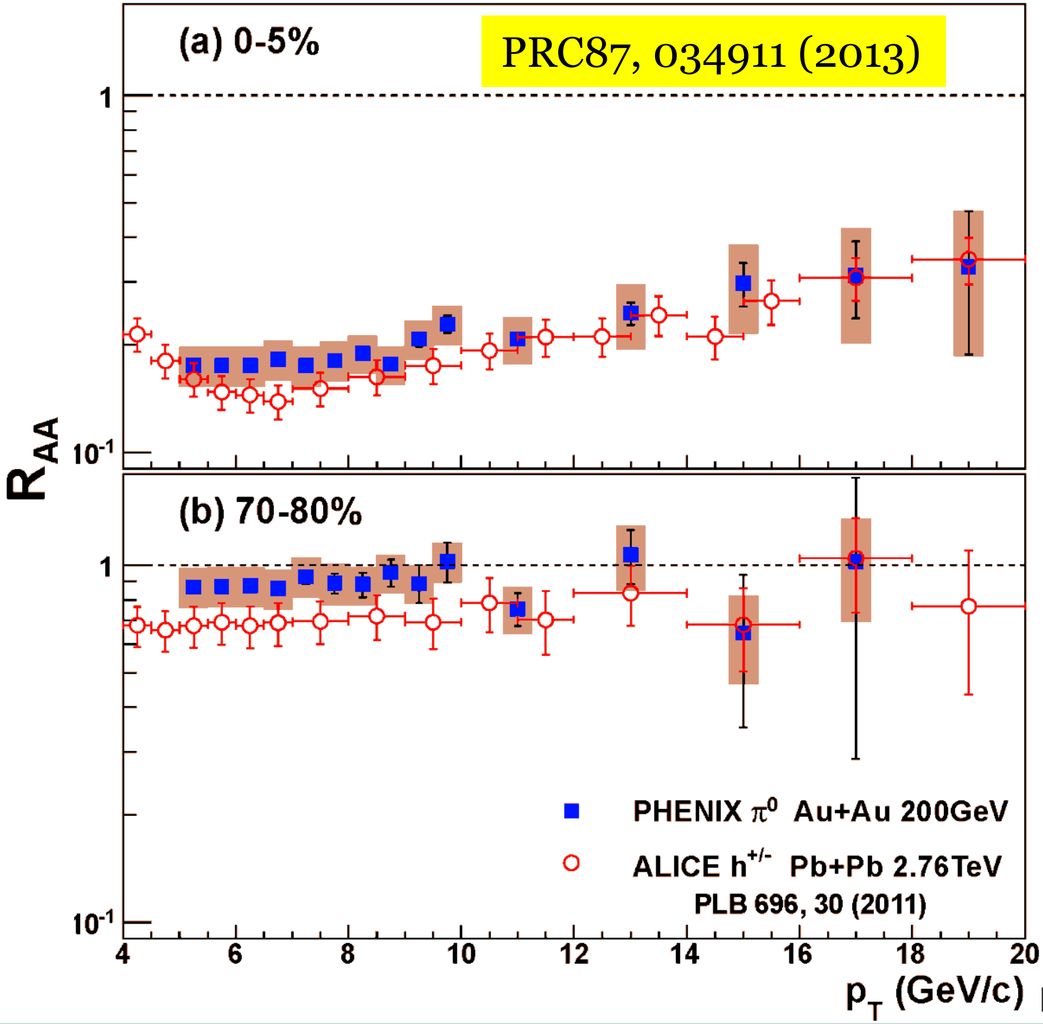
PRC82, 011902(R) (2010)



PRC87, 034911 (2013)

Characterization of Energy Loss

- R_{AA} very similar from 200 *GeV* (RHIC) → 2.76 *TeV* (LHC)
- Parton energy loss <u>expected</u> to depend on
  - System size
  - Collision energy



Characterization of Energy Loss

- R_{AA} relatively insensitive to variations of energy loss
- p_T^{-n}-shaped spectra → n changes fast with collision energy: n(62GeV) ≈ 11, n(200GeV) ≈ 8, n(2.76TeV) ≈ 6
- Instead of R_{AA} measure fractional momentum loss of high p_T hadrons

$$\Delta E/_{E} \sim \delta p_T/_{p_T} \equiv S_{loss}$$

Characterization of Energy Loss

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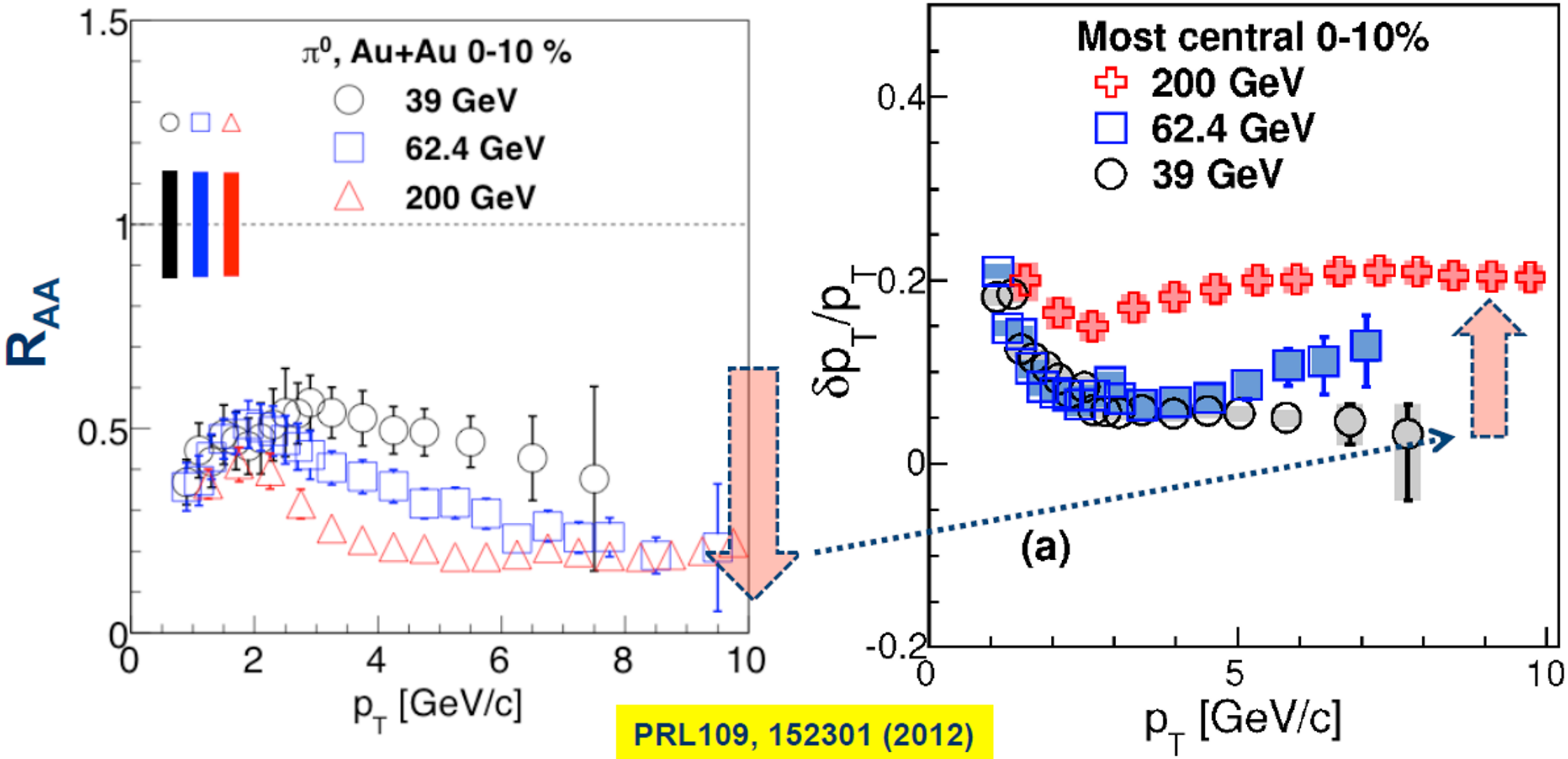
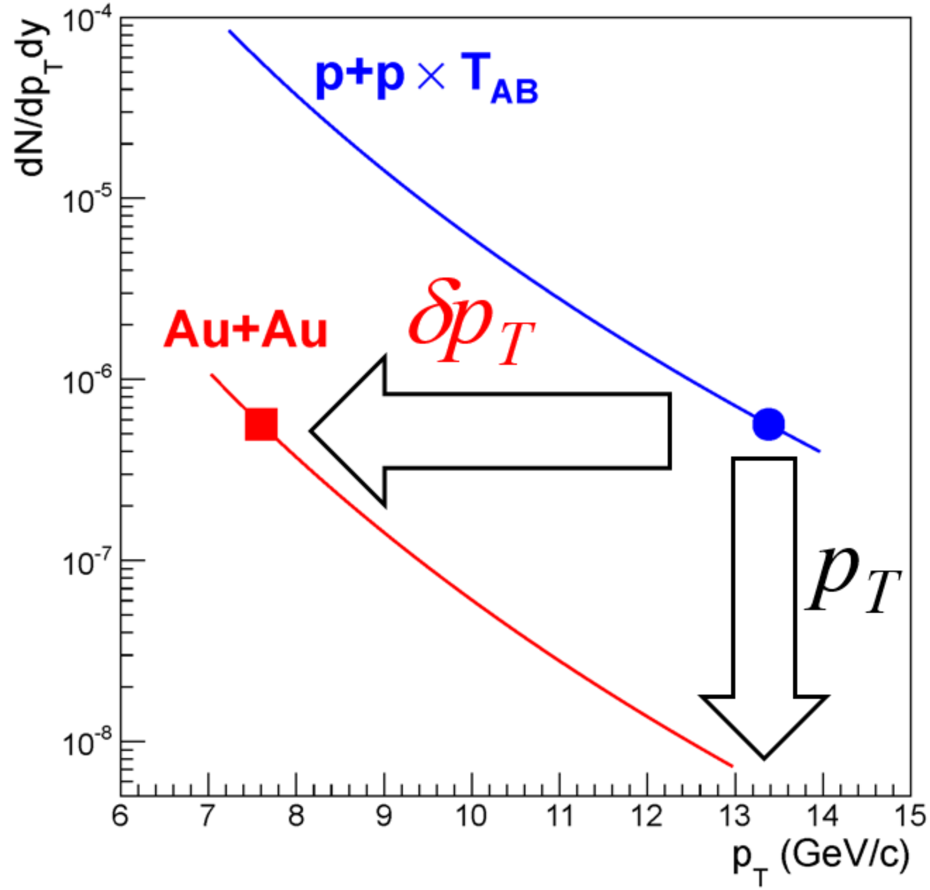


Fractional Momentum Loss

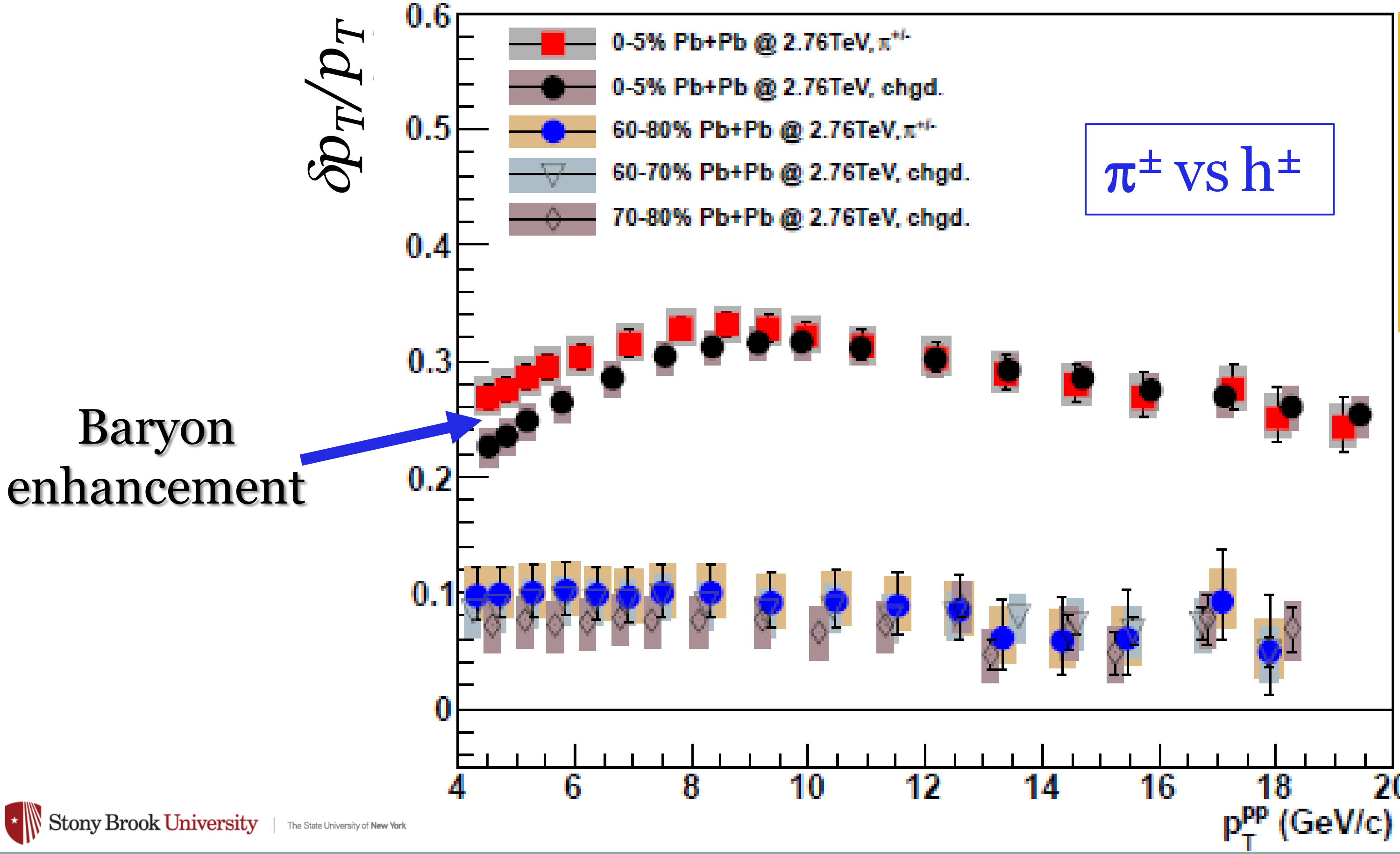
- N_{coll} scaling + FF unchanged
- Scale p+p data (σ_{π^0}) with T_{AA}(centrality)
- Fit p+p data
  - shift scaled p+p point closest in yield to A+A
- $p_T^{scaled}(p+p)$ - $p_T(A+A)$
- Relate to

$$p_T^{scaled}(p+p) \rightarrow \delta p_T/p_T$$



Fractional Momentum Loss @ 2.76 TeV

- $S_{loss}(p_T)$ for $h^{\pm}$: ALICE Pb-Pb 2.76 TeV



S_{loss} computed by PHENIX based on PLB736

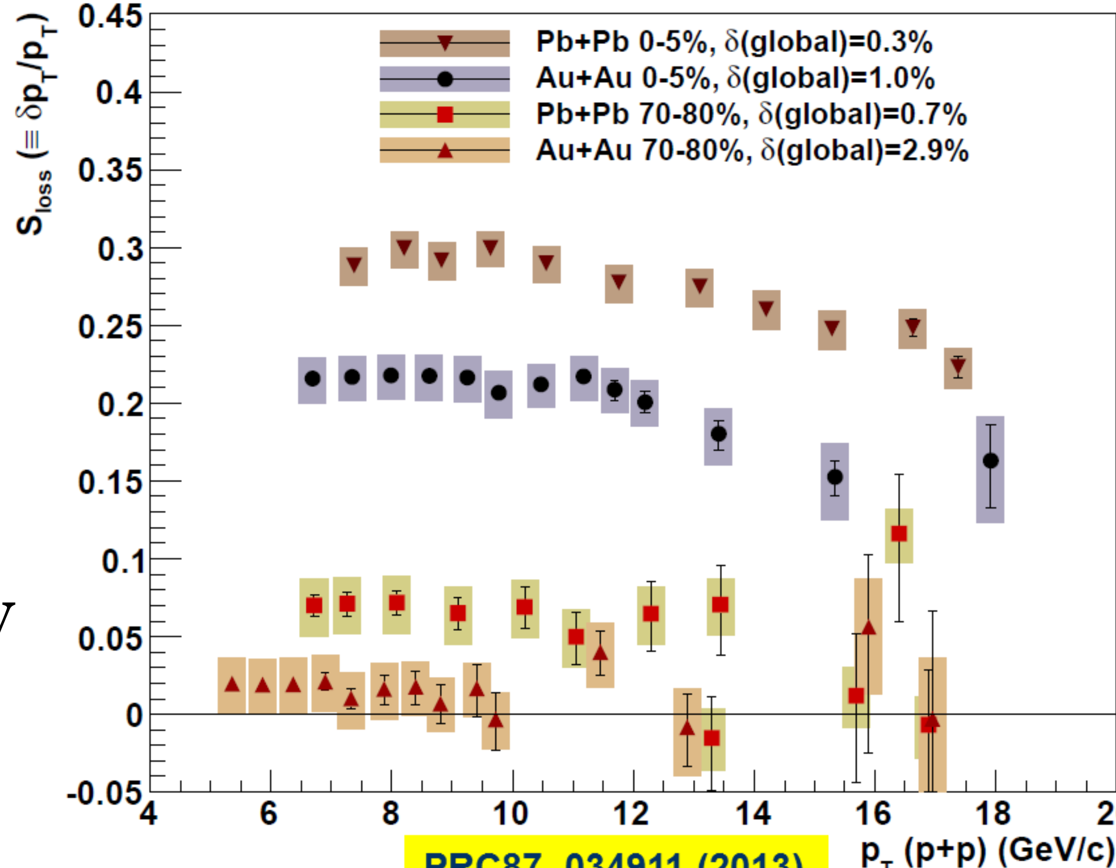
Fractional Momentum Loss 0.2 TeV vs. 2.76 TeV

- $S_{loss}(p_T)$ for

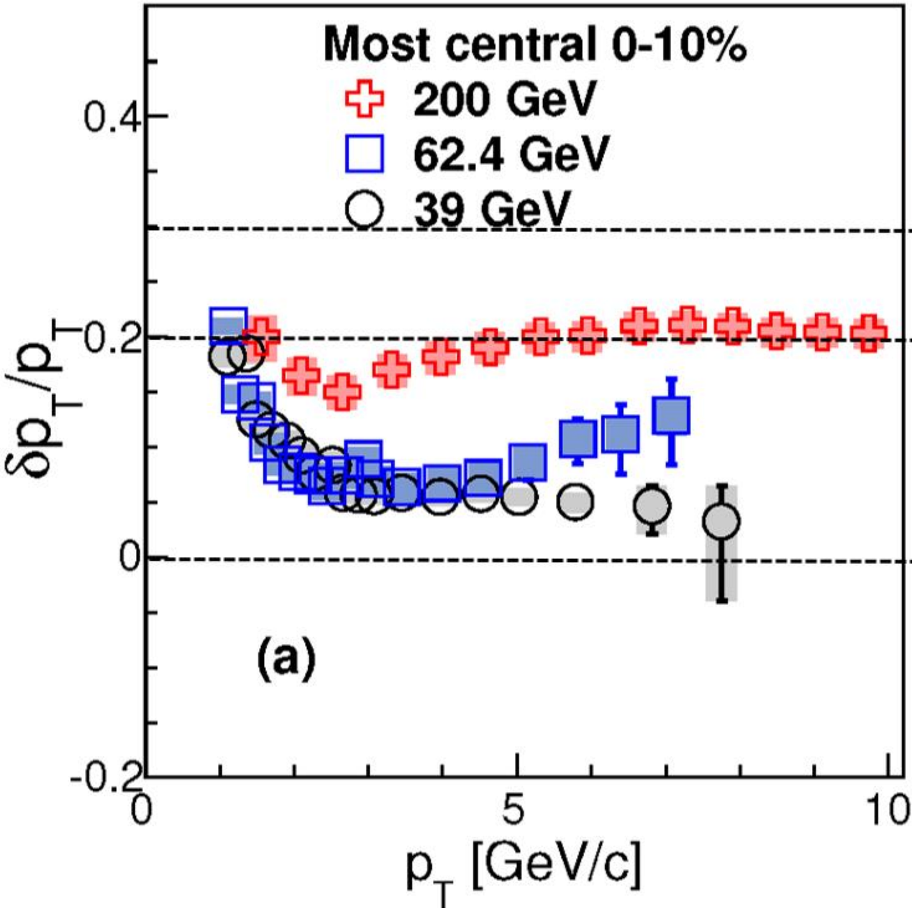
π^0 :PHENIX Au-Au 200 GeV

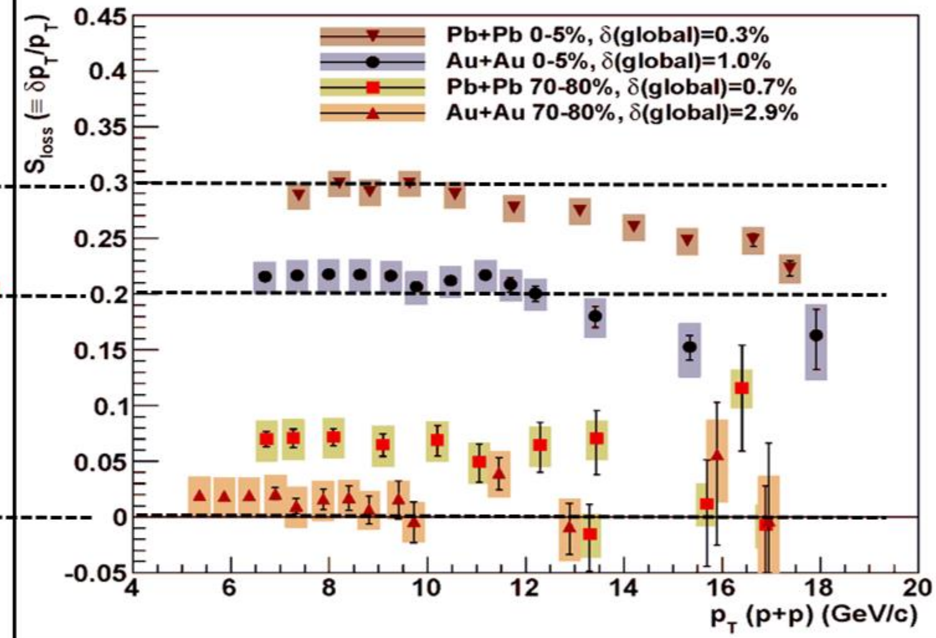
$h^{\pm}$: ALICE Pb-Pb 2.76 TeV

at the same centrality selections



Fractional Momentum Loss 0.2 TeV vs. 2.76 TeV





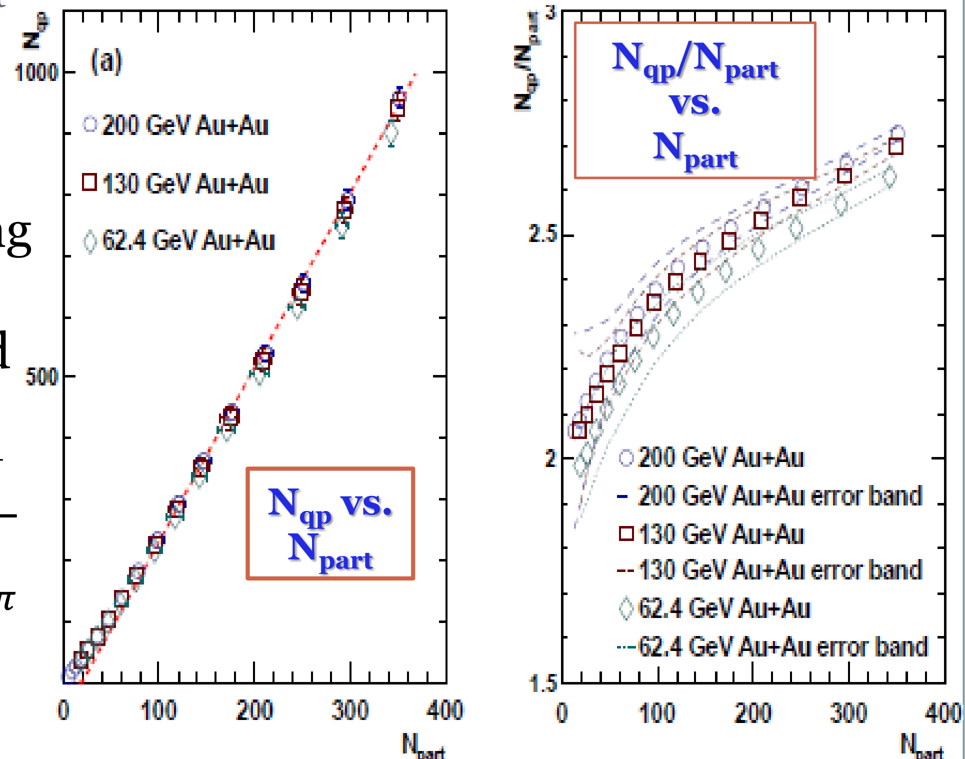
Systematic Studies with Scaling Variables

- Systematic studies of fractional momentum loss by means of ***scaling variables***
  - Number of nucleon and quark participants N_{part} and N_{qp}
  - Bjorken Energy density
  - Charged particle multiplicity $dN_{ch}/d\eta$

Scaling Variables

- Glauber-MC
  - estimates # nucleon-participants per centrality N_{part}
  - modify Glauber-MC for N_{qp} with quark-quark as fundamental interactions:
    - Nucleons distributed according Woods-Saxon
    - Quarks are distributed around N-center
      $\rho(r) = \rho_0^N e^{-ar}, \; a = 4.27\ fm^{-1}$
    - Quarks interact if $d < \sqrt{\sigma_{qq}^{inel}/\pi}$
    - Vary $\sigma_{qq}^{inel} \rightarrow$ reproduces σ_{NN}^{inel}

$\sqrt{s_{NN}}$ (GeV)	$\sigma_{NN}^{\text{inel}}$ (mb)	$\sigma_{qq}^{\text{inel}}$ (mb)
2760	64.0	18.4
200	42.3	9.36
62.4	36.0	7.08

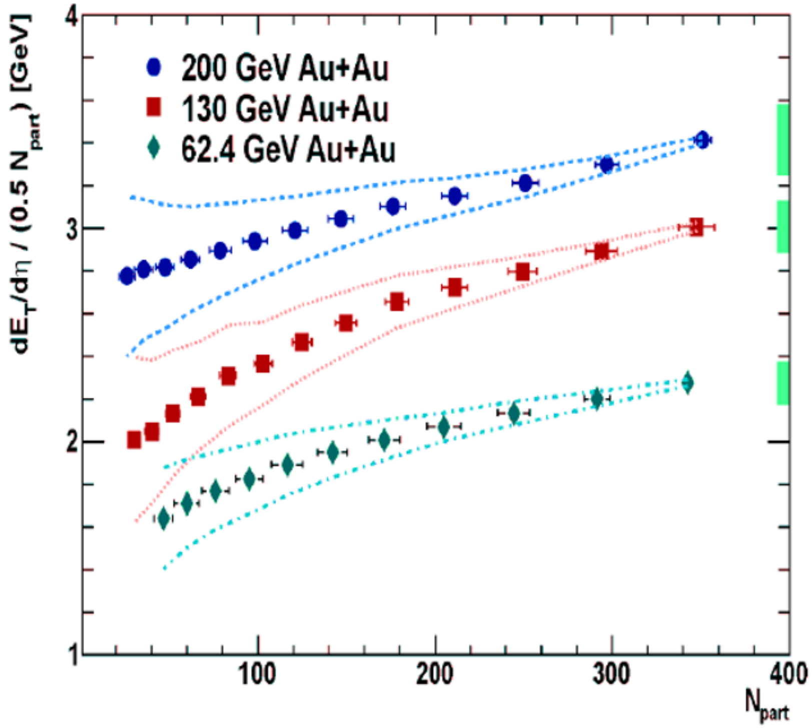


PRC89, 044905 (2014)

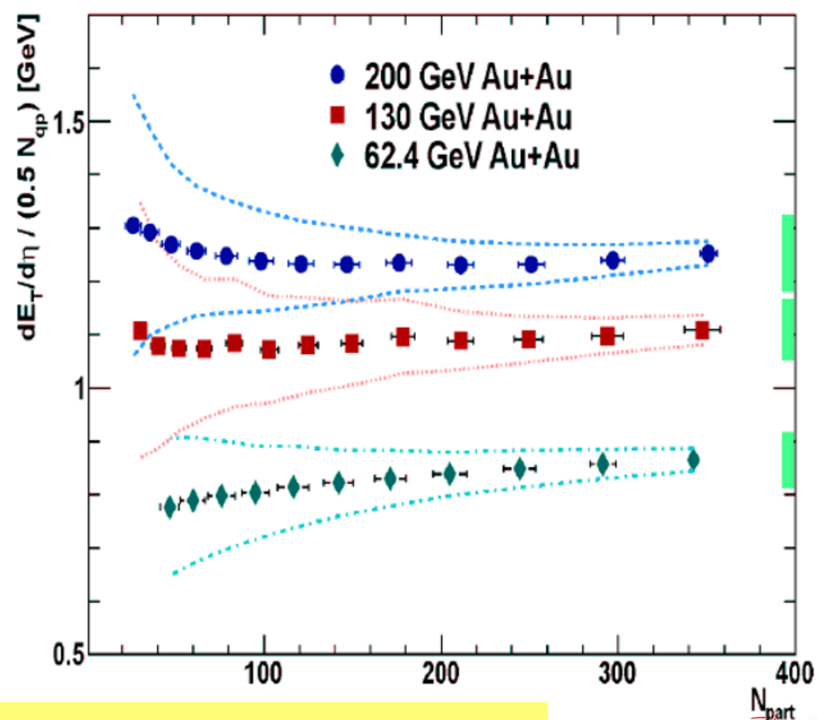
Scaling Variables

- $dE_T/d\eta$ scales better with N_{qp} than N_{part}

$dE_T/d\eta/(N_{part}/2)$ vs. N_{part}



$dE_T/d\eta/(N_{qp}/2)$ vs. N_{part}



PHENIX, PRC89, 044905 (2014)

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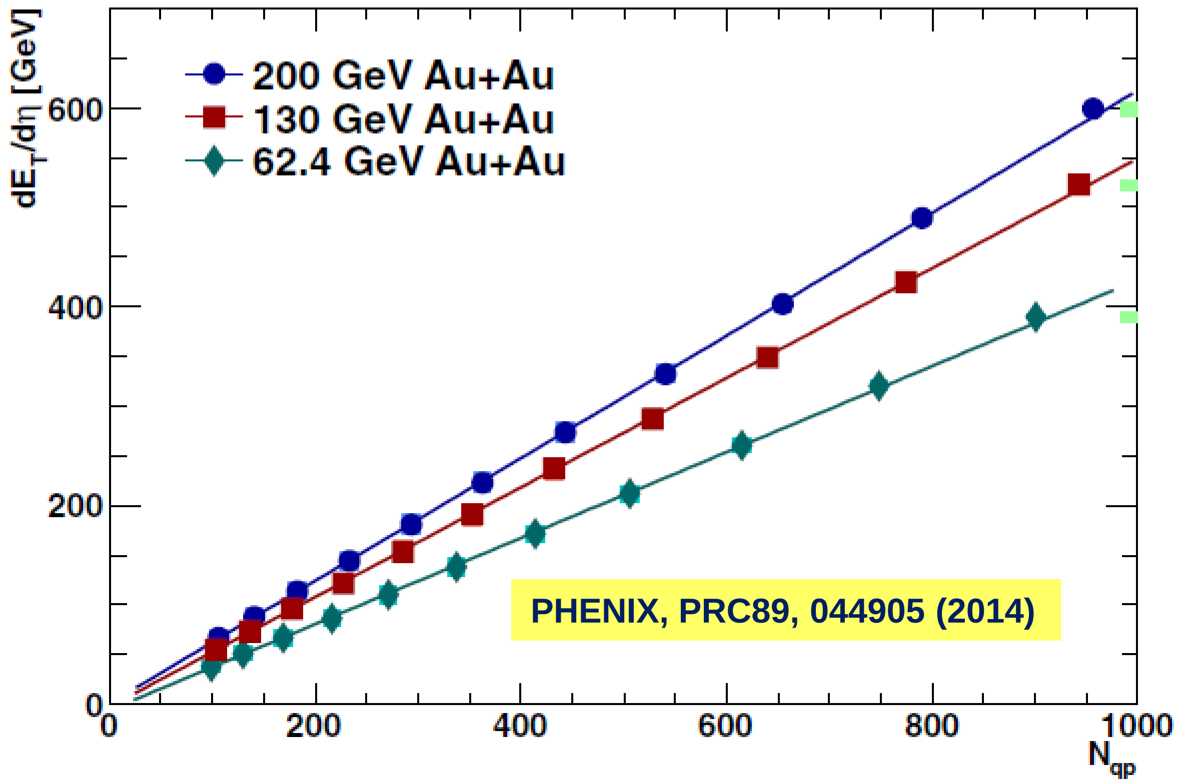

Scaling Variables

- Bjorken Energy Density
  - $\epsilon_{Bj} := \frac{1}{\tau A_{\perp}} \frac{dE_T}{dy}$
    - τ: proper time at QGP_{equil} → strongly model dependent
    - $A_{\perp} \sim \sigma_x \sigma_y$: transv. size (from Glauber-MC)

  $\Rightarrow \epsilon_{Bj} \times \tau = \frac{1}{A_{\perp}} \frac{dE_T}{dy}$ contains only well-established experimental quantities
  - ALICE-data from J.Phys. G38
- Charged Particle Multiplicity
  - PHENIX measured $dN_{ch}/d\eta$ at $|\eta| < 0.35$, no magnetic field
  - ALICE-data from PRL 106, measured with Silicon Pixel Detector at $\eta < 0.5$

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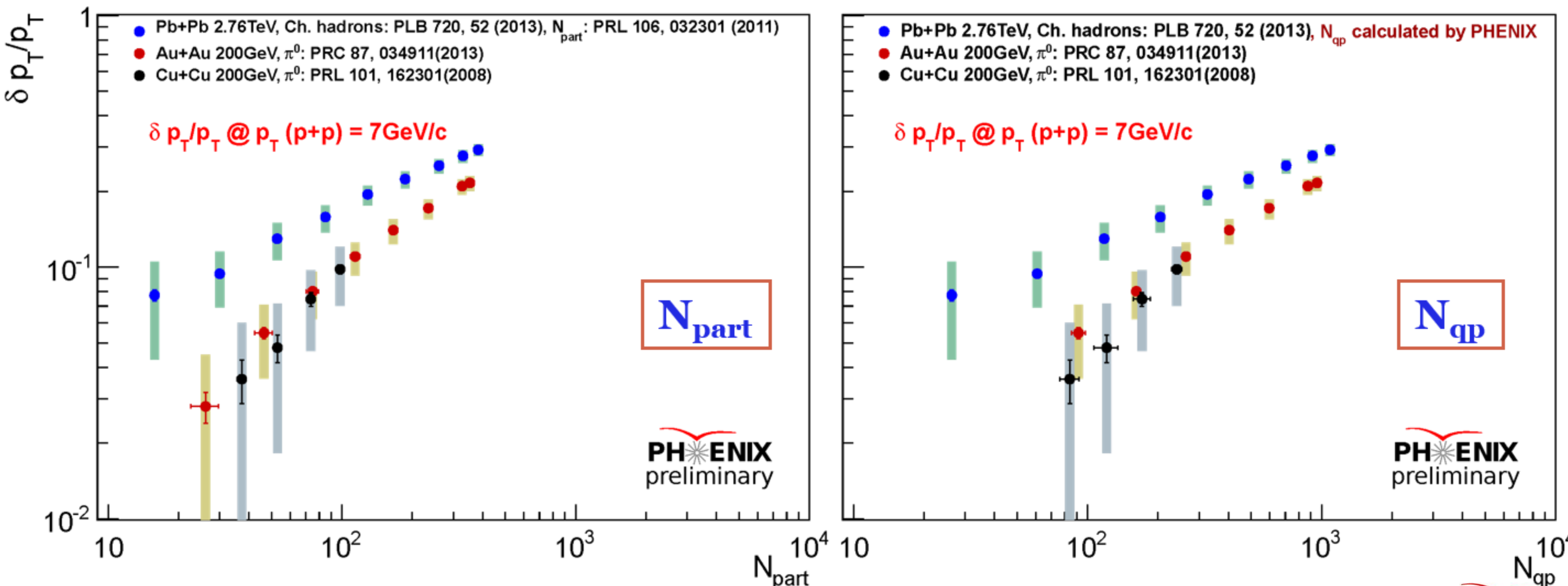
Scaling Variable Dependence

- Fractional momentum loss vs. N_{part} and N_{qp}

  $\delta p_T/p_T$ for $p_T^{scaled}(p+p) = 7$ GeV/c

  N_{part} and N_{qp} according to centralities



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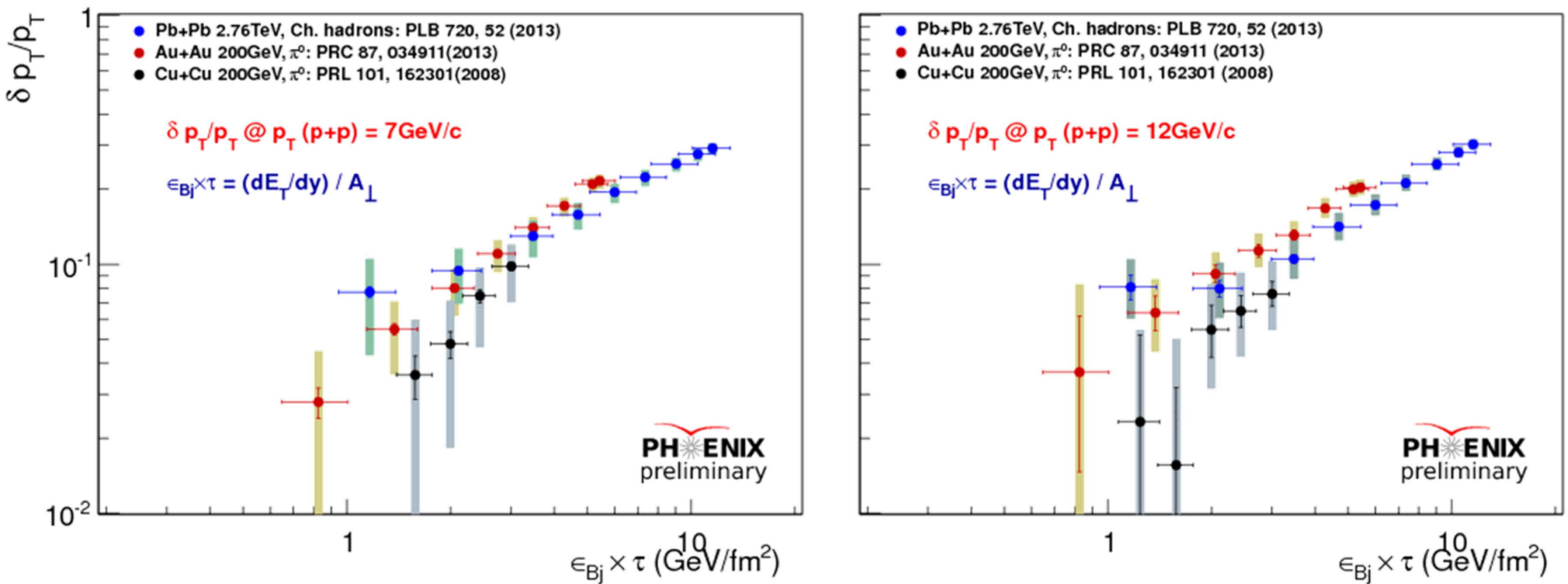
Scaling Variable Dependence

- Fractional momentum loss vs. $\boxed{\epsilon_{Bj} \times \tau}$

  $\delta p_T/p_T$ for $p_T^{scaled}(p+p)$= 7 and 12 GeV/c

  Bjorken Energy density according to centrality

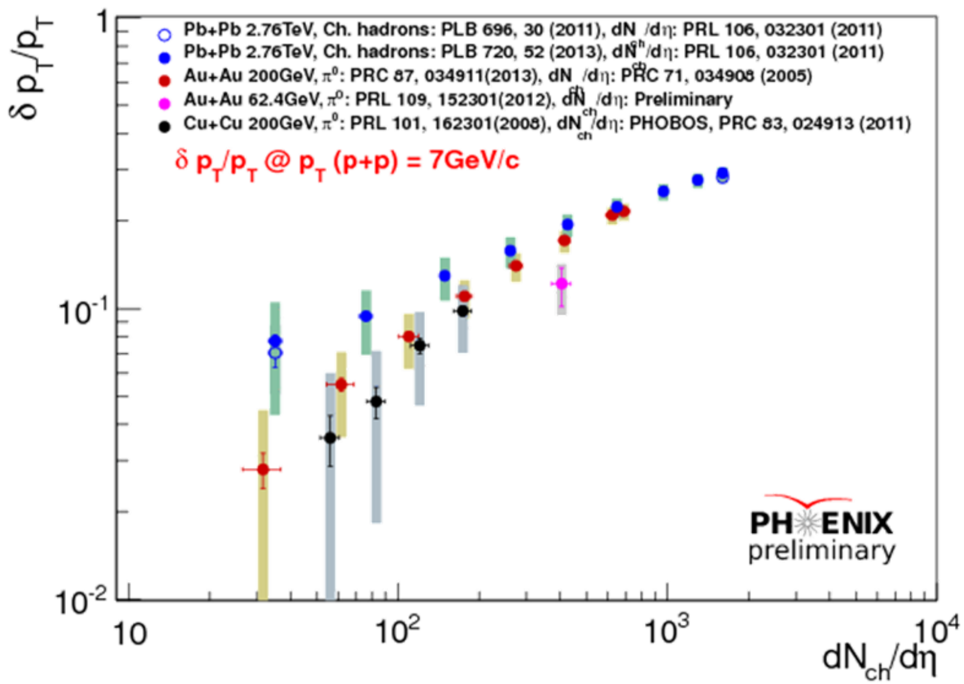


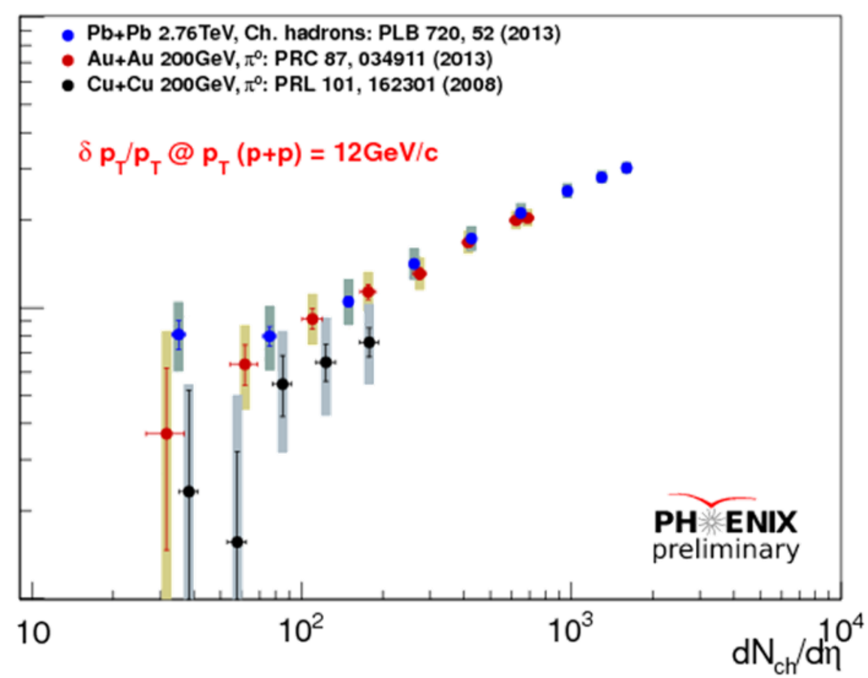
Scaling Variable Dependence

- Fractional momentum loss vs. $\boxed{dN_{ch}/d\eta}$

  $\delta p_T/p_T$ for $p_T^{scaled}(p+p) = 7$ and 12 GeV/c

  Charged particle density corresponding to centrality





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Summary and Conclusion

- Fractional momentum loss S_{loss} might be more sensitive tool than R_{AA} to compare different colliding systems → removes spectra-shape bias
- We are working to determine the dependence on parameters $\delta p_T/p_T^{pp} = \beta(scaling\ var.)^{\alpha}$
- In p_T region where hard scattering is expected to dominate S_{loss} exhibits simple scaling with global observables
- S_{loss} as a function of $dN_{ch}/d\eta$ or $\varepsilon_{Bj}\, x\, \tau$ consistent between highest energy RHIC-results and LHC

→ good scaling variables